Factors that influence the speed of bacterial wood degradation

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Abstract
Bacterial wood decay is a serious threat to the many wooden foundation piles in the Netherlands. In order to learn more about the factors that influence the process of decay app. 2000 wood samples taken from Amsterdam piles were analysed on type and degree of decay. Although large scale differences in soil constitution (between cities) are a factor in the process of wood decay, on micro scale (within Amsterdam), no influence is found that explains the variety in degree of decay. Differences in wood quality (growth rate, origin, process of harvesting) are regarded as more important in causing the variety in degree of degradation in piles of a same location.

1. INTRODUCTION

As a consequence of the wet and unstable soil conditions, in the Netherlands many houses are standing on foundation piles. Although the concrete pile replaced the wooden pile rapidly after WO II, it is estimated that still 25 million wooden piles are in use. Half of these piles are carrying buildings and the other half water constructions (e.g. quay walls, bridge headings). From the old days onwards it was required that the wooden pile head is always under the ground water level and under the ground water table wood degradation is exclusively caused by erosion bacteria [1]. Most historic buildings in cities in the western part of the Netherlands are standing on wooden foundations piles with many of them exceeding 300 years of age. However, the majority of the wooden piles originated from 70 to 150 years ago. Around 1875, during the industrialisation period, a rapid expansion of most cities started with the consequence that until ca. 1960 large volumes of wooden piles were used.
Two decades ago large scale problems appeared with the stability of foundations under family houses. At the moment, these problems are known for app. 200.000 houses divided over 150 cities including Amsterdam, Dordrecht, Gouda, Haarlem, Rotterdam and Zaandam. Main part of the problem is caused by bacterial decay but another significant part is caused by a too low ground water table. The mean costs of foundation repair are € 60.000,- and can cause severe financial problems for the house owners [2]. Nevertheless the Dutch government does not give any support in solving this problem. Probably because of the huge financial implications (estimation of the cost on national level > € 10 billions) and the fact that it is a non-visual issue as foundation repair is not visual afterwards.
In order to avoid collapse of house, inspections are requested of wooden foundation piles, when houses are sold or when houses are under construction. Unfortunately foundation inspections are not done automatically, resulting sometimes in unexpected high financial cost for the last house owner. Main goal of a foundation inspection is to give an estimation of the actual quality and the quality in the next 25 years. During the foundation inspections wood samples are taken with an increment borer and in the laboratory, the degree and pattern of decay is determined. During the last 15 years sample information has been collected on the condition of more than 5000 foundation piles originating from different locations in the western part of the Netherlands. Together with laboratory experiments this comprehensive database was used for a better understanding of the process of bacterial decay. Earlier studies show that spruce and pine are beside alder, fir, poplar and oak the most common species used in the Netherlands and it appeared that all piles, older than 5 years, are degraded by bacteria at least in the outer most wood layer and that the velocity of bacterial degradation is highly variable and ranges between 0 - > 1 mm/year [3] [4]. As a relationship with permeability is expected, variation in decay velocities can partly be explained by the timber species used: poplar, alder, and pine sapwood are more susceptible to bacterial degradation than heartwood of oak, pine, douglas and larch [5]. An interaction between the wood permeability and soil hydrology is suggested which could explain the variation in bacterial decay velocity [6]. This is illustrated by the piles from Rotterdam, were bacterial decay is less active compared to the piles of many other cities (e.g. Amsterdam) [3]. In order to check whether soil hydrology can explain variations within cities, 2000 records from the database originating from Amsterdam were analysed.

2. METHOD

On the basis of the postal codes each record in the database was given x and y coordinates. If more than one pile appeared on one address the x-y coordinates where changed for some meters in order to

avoid more than one pile on the same coordinates. From the database information was extracted on service life (years in soil), depth of bacterial decay (measured from bark side inwards) in two degrees (severe and weak) and timber species. This information was plotted over the map of Amsterdam using Top10Smart 2006 (copyright: Alterra-WUR).
Furthermore a map of Amsterdam was made with groundwater data, based on piezometric levels (m) from observation wells of the upper groundwater (phreatic water) and the deeper groundwater (first sandy soil layer). Subtracting of the two levels results in the difference in hydraulic head (m), that indicates the pattern in differences in hydraulic heads and the direction (upward or downward) of the seepage. These differences in hydraulic heads where used as groundwater.
In addition to the information from the database information of 8 extracted piles from one location and preliminary data of piles originating from the Royal Palace on the Dam square were added.
The extracted piles originated from the Czaar Peterstraat in Amsterdam, were app. 12 m long and were 118 years in service. Information on the degree of decay as well as on the number of yearrings was available for the top and tip of the piles.
During restoration in 2007 of the Royal Palace three pile heads where removed and stored under dry conditions over more than two years. Recently a clear cross cut was made of one piles and the degree of decay over the pile diameter was determined.

3. RESULTS AND DISCUSSION

3.1. Database with app. 2000 Amsterdam records

The majority of the Amsterdam records where samples of pine and spruce. Therefore only these two species are taken into account. In figures 1 and 2 the map of Amsterdam and the distribution of both species are shown.

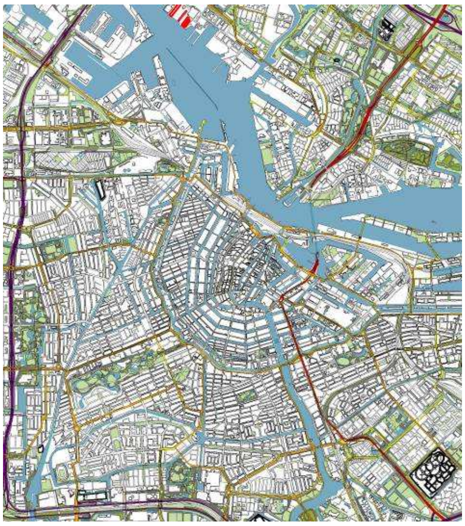

Figure 1: map of Amsterdam with locations of piles

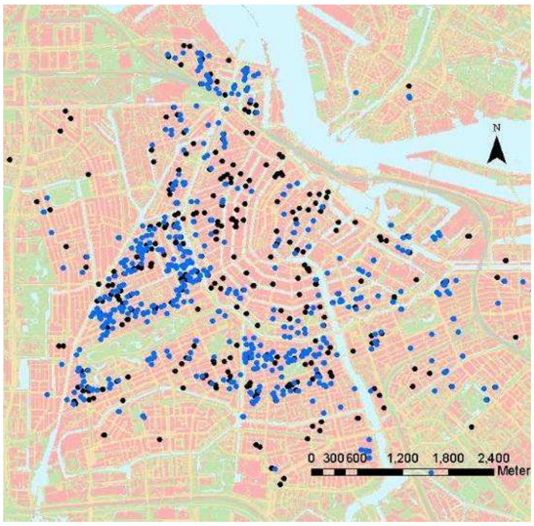

Figure 2: map of Amsterdam where most foundation with wooden piles exists and the distibution of the timber species
● spruce ● pine

In figure 3 the service life for each pile is given. The oldest piles are found in the down town area but it has to be realised that some of these piles are much older then 140 years (e.g. the Royal Palace on the Dam square and the Maritime museum both app. 350 years old). Around the down town area clusters of same-age piles can be seen, illustrating the expansion of Amsterdam in time. However within restricted areas the service life of the piles varies a lot, e.g. Vondelpark and Sarphatipark area (within a cluster of several streets the service life differs as much as 60 years).

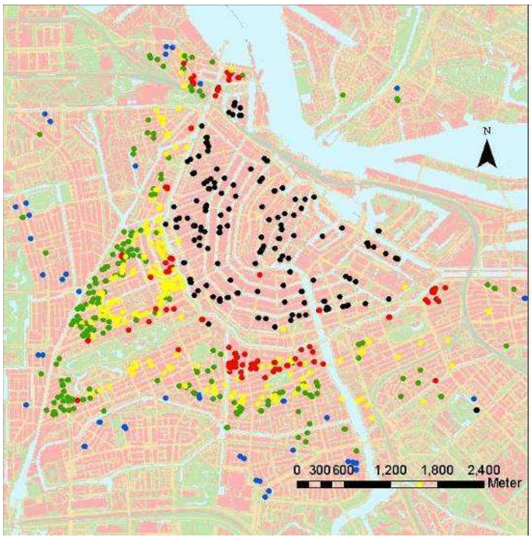

Figure 3: Map of Amsterdam with locations and service life of spruce and pine piles
● 60-80 year ● 80-100 year ● 100-120 year ● 120-140 year ● 140 -> year

The velocity of bacterial decay in the top of app. 1000 spruce and 1000 pine wooden piles with a service life of 80 – 200 years was calculated. The velocity was differentiated for severe as well as for weak decay (according to the classification of Klaassen 2008). In severely degraded timber the compression strength is significantly reduced whereas in weak degraded timber there is no or only limited strength reduction. As the invasion of wood degrading bacteria is from the outside inwards, weakly degraded timber is regarded as the deepest point of bacterial invasion in the timber.

For both timber species, first frequency diagrams were made for the velocity of the deepest invasion and severe degradation (fig. 4 - 7). In pine piles an invasion velocity of around 0.5 mm/year was most frequent, whereas in spruce most frequent velocity ranges between 0.1 - 0.5 mm/year. Furthermore the maximum velocity in pine was much higher than in spruce. For the velocity of severe decay a similar but more pronounced pattern was observed. In pine piles a velocity of 0.25 mm/year was most frequent whereas in spruce it ranges between 0 – 0.5 mm/year. Highest velocities are found in pine. All graphs give relative high frequency of velocities of 0 mm/year but these values should be regarded as sampling failure. As most samples are taken with an increment borer (Ø 10 mm) it can be imagined that the most (rotten) outside part can be lost during extracting of the core from the borer. Beside an estimation of the velocities with the highest frequency, also the mean velocity is calculated. The overall mean severe bacterial degradation velocity in pine is 0.25 mm/year and for spruce it is 0.13 mm/year.

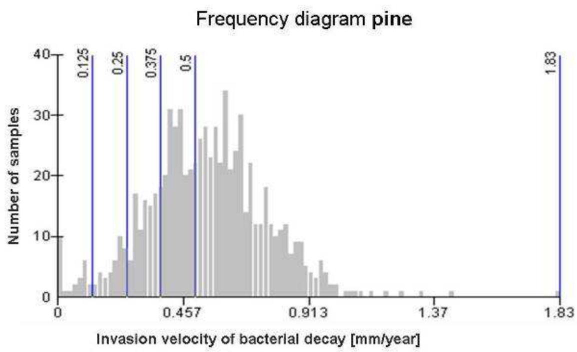

Figure 4: frequency diagram of bacterial invasion velocity in pine

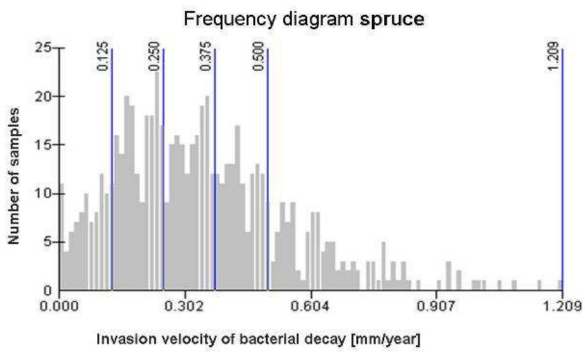

Figure 5: frequency diagram of bacterial invasion velocity in spruce

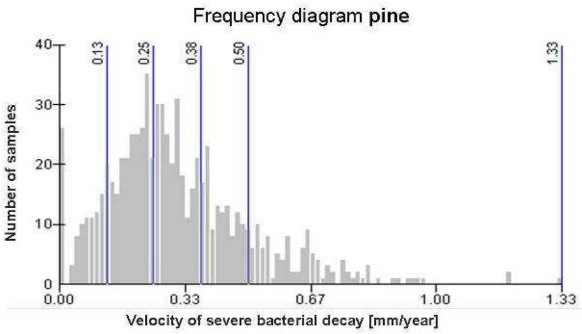

Figure 6: frequency diagram of the velocity of severe bacterial degradation in pine

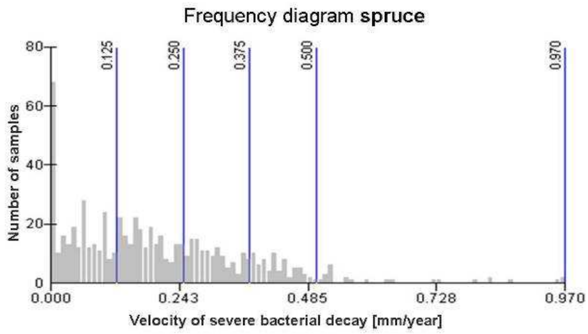

Figure 7: frequency diagram of the velocity of severe bacterial degradation in spruce

From figures 4 - 7 it becomes clear that spruce has a different resistance against bacterial decay than pine. Therefore separate maps of each timber species were made. A differentiation between invasion velocity and the velocity of severe decay is necessary in order to deal with the influence of heartwood and sapwood. Pine sapwood is sensitive for bacterial decay whereas pine heartwood has a high resistance. For foundation piles highest velocities of decay are found in pine sapwood whereas in pine heartwood the velocity is zero or almost zero [3]. Also for spruce it is believed that there is a difference between sapwood and heartwood in resistance against bacterial decay. Unfortunately the heartwood – sapwood boundary in spruce foundation piles after several decades in function can not be distinguished easily, and therefore the decay-velocity found in spruce is a mixture of the velocity in sapwood and in heartwood. Sapwood statistics of spruce could offer an opportunity for a better differentiation.
Preliminary research on one of the foundation piles underneath the Royal Palace in Amsterdam give evidence that in spruce heartwood the velocity of bacterial decay is strongly decreased. In figure 8 a cross section of a dried pile disk from the Royal Palace is shown. One outside peal of app. 1-2 cm shows collapse because of severe bacterial decay but the inside of the disk is sound. The boundary of the degraded wood gives the impression that it follows, at least partly, the sapwood – heartwood boundary. It is partly concentric and shows branch scars.

Figure 8: disk (Ø 160 mm, ca. 70 yearsrings) from one of the piles underneath the Royal Palace on the Amsterdam Dam square which was 350 year in service

We know that the depth of the bacterial invasion in pine piles extends mostly no further than the sapwood – heartwood boundary, occasionally less deep but never reaches into the heartwood. The rate of invasion velocity calculated is therefore underestimated. In many pine piles the depth of severe bacterial decay is less than that of the depth of the invasion of wood degrading bacteria and can be regarded as active. In spruce the influence of the sapwood – heartwood boundary in piles of app. 100 years in service is less clear.

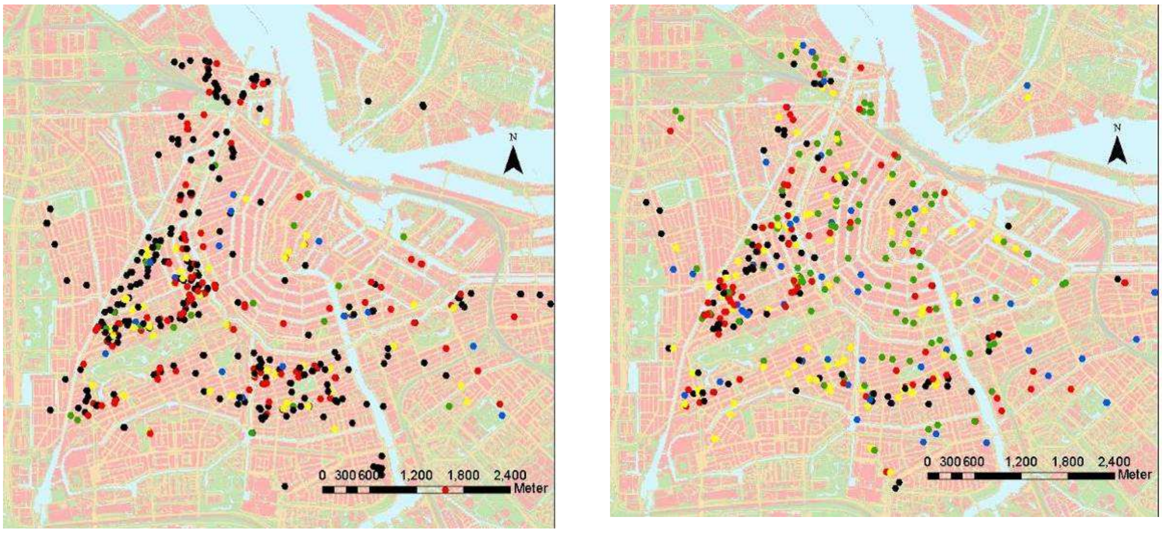

Figure 9 and 10: map of Amsterdam with locations and invasion velocities of wood degrading bacteria in pine (left) and spruce (right) foundation piles [mm/year].
0.00 - 0.12 | 0.13 – 0.25 | 0.26 – 0.37 | 0.38 – 0.5 | 0.51 - > 1

In order to get an idea of the activity of the bacterial decay for each timber species two maps are made: one with the invasion velocity and one with the velocity of severe bacterial decay. The maps for pine (fig. 9 and 11) and those of spruce (fig. 10 and 12) differ strongly form each other. For both species many black and red dots are seen in figures 9 and 10 and a dominant appearance of blue and green dots in figures 11 and 12, meaning that bacterial wood decay is active in many piles.
The different sensitivity of spruce and pine against bacterial decay is confirmed by figures 9 -12. For the invasion velocity much more black and red dots are seen for pine whereas for spruce much more blue and green dots are visible. For the velocity of severe bacterial decay the blue dots are dominant in the spruce map (fig. 12) whereas in the map for pine more variety in dots colour is seen in figure 11 meaning that a wider range of velocities exists.

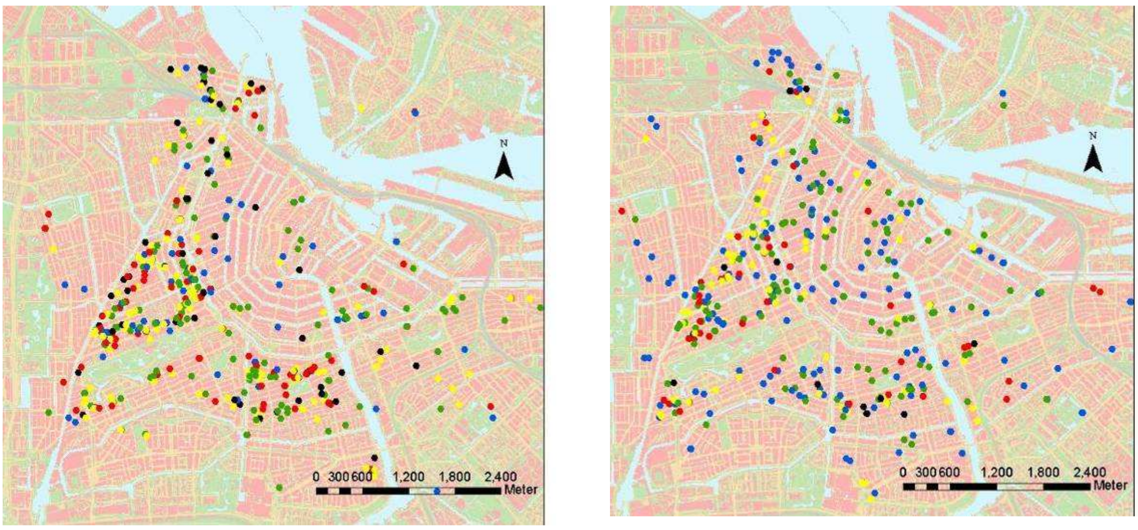

Figure 11 and 12: map of Amsterdam with locations and velocities of severe bacterial decay in pine (left) and spruce (right) foundation piles [mm/year].
0.00 - 0.12 | 0.13 – 0.25 | 0.26 – 0.37 | 0.38 – 0.5 | 0.51 - > 1

The maps with bacterial invasion show in general higher velocities than the maps of severe decay which means that at least for severe decay a boundary towards highly resistible wood against bacterial, is not reached yet and the decay can be regarded as active in most piles. Therefore the velocities of severe decay are most discriminative. Looking at the maps of severe decay (fig. 11 and 12), it is remarkable that there are no areas where pile clusters appear with a homogeneous high or low velocity. However the old town gives the impression that the velocities are lower. Around the old town of Amsterdam there are locations where the velocity of bacterial decay is homogeneous but there are also locations where there is a great variety. Figures 13 – 16 illustrate this on a more detailed scale. The finding of high and low velocities on the same area means that there should be other parameters influencing the activity of bacterial wood degradation than soil conditions.

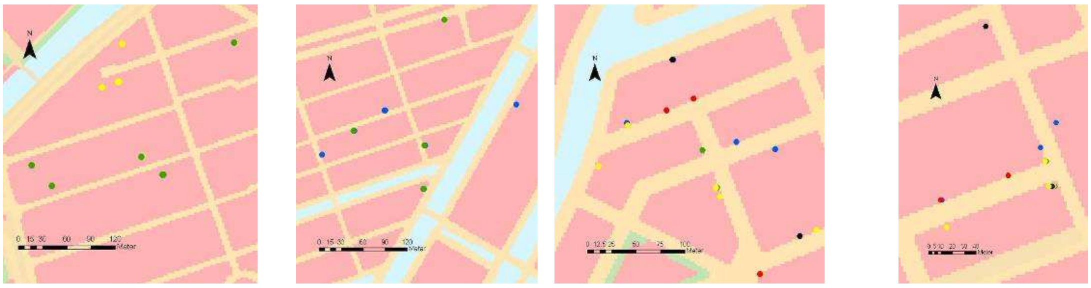

Figure 13 – 16 detail maps of areas in Amsterdam, the two most left maps (pine and spruce) show areas where the velocity of severe bacterial decay is more or less homogeneous and the two most right maps (pine and spruce) show areas where the velocity strongly varies [mm/year]

0.00 - 0.12 | 0.13 – 0.25 | 0.26 – 0.37 | 0.38 – 0.5 | 0.51 - > 1

In figure 17 a map of Amsterdam is shown with the pattern of the pressure of the deeper ground water. No relation could be found with the variety in degradation speed. Only in one area in Amsterdam (Watergraafsmeer) with a high pressure of the deeper ground water several piles where found in which the velocity of bacterial decay was zero or almost zero. It is suggested that only here the positive ground water pressure and salt concentration from the deeper ground layers could be the cause of these low velocities.

Figure 17: Map of Amsterdam with difference in pressure between the upper and deeper ground water [m]

-2.02 to -2 | -1.9 to -1.0 | -0.9 to 0.0 | 0.01 to 1.0 | 1.01 to 2.0 | 2.01 to 3.0

3.2. Preliminary study on bacterial decay over the pile length

In [7] it is mentioned that bacterial decay appears always at the top as well as at the tip of a foundation pile. They investigated 26 piles in Haarlem, Stockholm, Amsterdam, Rotterdam, and Zaanstad covering the species spruce, pine, fir and poplar. In order to get more detailed information on the difference in degree of degradation over the pile length, the eight extracted spruce piles were analysed (fig. 17 - 20). Mean velocity of the invasion speed at the pile top is 0.16 mm/year and for severe decay it is 0.10 mm/year. Figure 18 shows a gradient in decay depth from top to tip. For the invasion depth this gradient is less clear while two piles deviate with a transfer gradient and in one pile the velocity at the tip and top of the pile is similar. Explanation of different patterns, could not directly explain by the grow dynamics of the trees. As the diameter of all piles are more or less similar, figure 19 show that fast growing trees (young ones < 40 years old) as well as slower grown trees (older ones >80 year) were used. The growth rate in tree length was also variable (< 1 m/year to almost 6 m/year, see fig. 21). The number of samples is too low to allow statistical tests but these findings proof that variety in wood quality within piles of a same location can be wide (fig. 20 - 21). Further research with a more extensive sample set is needed to investigate the relationship between bacterial decay of the pile head and over the pile length in more detail.

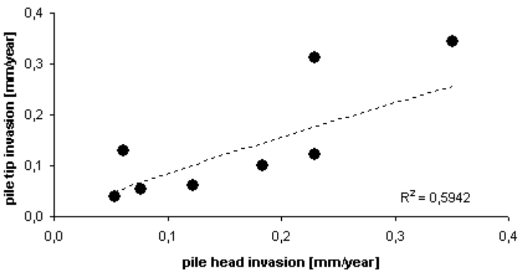

Figure 17: relation between invasion velocity between the tip and top of spruce foundation piles

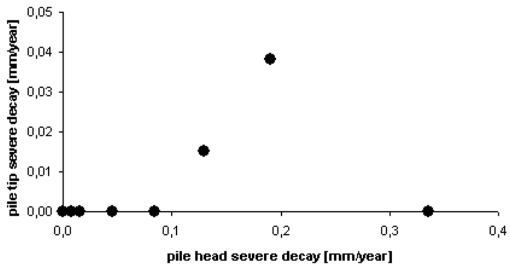

Figure 18: relation between the velocity of severe bacterial decay between the tip and top of spruce foundation piles

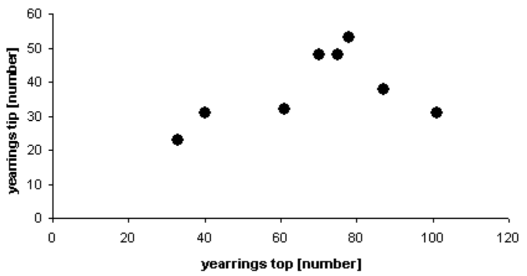

Figure 19: relation between number of yearrings between top en tip of a pile

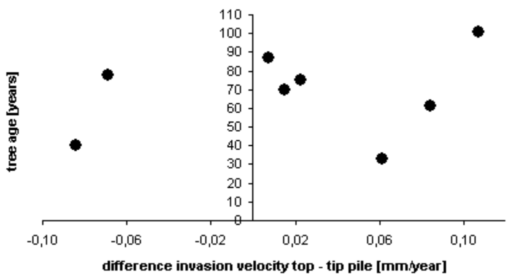

Figure 20: relation between tree age and differences in invasion velocity between pile top and tip

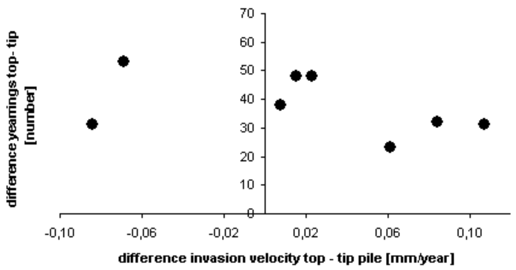

Figure 21: relation between number of yearrings and invasion velocity illustrated on the differences between top and tip values

3. CONCLUDING REMARKS

Although large scale differences in soil constitution (between cities) are a factor in the process of wood decay [3] [8], this study shows that piles from the same location have a wide variety in degradation speed at their tops as well as at their tips. Timber species and sapwood amount in pine are known parameters of influence on the process of decay but do not explain the variation seen here. Therefore other specific wood features should have their influence. Firstly, the differences in resistance against bacterial decay between spruce heartwood and sapwood could be one of the underestimated parameters as the 350 year old pile from the Royal Palace suggests its importance. Secondly, tree growth can be regarded as influence, as shown from the extracted piles which have a wide variety in growth rate (yearring-width, shoot-length). Thirdly, the historical record mentions differences in harvesting and origin of the foundation piles. Winter as well as summer harvesting was common, Northern, eastern, middle Europe and the Netherlands were the main production areas and the time between harvesting and inserting in the soil differs from several days to several years [7].

All variables mentioned could have their influence on water movement through the wood, the key factor in stimulating bacterial wood decay.
Additional proof pointing towards water movement as key factor is found in foundation constructions where wood is used in combination with concrete. After 1950 the use of wooden piles with a concrete upper part became more and more dominant in order to avoid the risk of a too low ground water table around the wooden pile head. Several empiric observations show a remarkable thin layer of weak peal (i.e. bacterial degradation) around the pile and it is suggested that this is caused by the closure of the wood structure by concrete which sails the wood and prevents water movement. As, all samples studied here originated from full wooden foundations, this aspect is for this study of no importance, where as tree growth could affect the conducting area by amount of sapwood and early wood. The time between harvesting and pile installation affects the pit closure, drying of the timber and fungal colonisation. A supposed lower velocity of bacterial decay could be related to wood quality. From the historical records it is known that the origin of the piles changed over time and that the quality control for the expensive buildings in the old town followed a higher standard than the quality control of family houses from the surrounding areas.

Further exploration and understanding of the interaction between these aspects and bacterial wood decay would enable us be possible to improve our methods to estimate the lifetime of a foundation and to improve the selection of stems which are suitable for the use in foundations, which are an interesting carbon sink.

Acknowledgement
Thanks to Berdien van Overeem (WUR) making all maps and frequency diagrams; Ab Visser (Waternet, Amsterdam) for providing the groundwater data; Gabri van Tussenbroek (Bureau Monumenten en Archeologie, Amsterdam) for donating disks of the foundation of the Royal Palace on the Amsterdam Dam square; Marloes Remie (SHR) for doing the majority of the sample analyses; Ewald Pfeiffer (SHR) for doing the sample preparation of the extracted and Royal palace pile samples; Jos Creemers (SHR) for careful review of the text.

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